NASA-CR-204070

HIGHLY REUSABLE SPACE TRANSPORTATION

PROPULSION SYSTEM INFORMATION WORKSHEETS

PROPULSION SYSTEM Supercharged Ejector Ramjet with Maglifter Launch Assist (for the Argus concept)

DATA REFERENCE

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PROPULSION SYSTEM INFORMATION WORKSHEET

- **PROPULSION SYSTEM NAME**
  - **Argus** - SSTO HRST vehicle with SERJ RBCC engines and Maglev launch assist

- **PROPULSION SYSTEM TYPE**
  - Combined-Cycle Propulsion
- **PROPULSION SYSTEM DESCRIPTION**
  - Propulsion System Description - Main propulsion system consists of two 330 klb-class LOX/LH2 supercharged ejector ramjet (SERJ) RBCC engines. Engines are capable of multi-mode operation including supercharged ejector, fan-ramjet, ramjet, and pure rocket modes. A low thrust 'fan-only' mode is available for powered landing, go-around, taxi, etc. (5 minutes at full throttle).

    Baseline Maglifter launch assist system consists of a magnetically levitated sled and track system that accelerates the vehicle to approximately 800 fps. At an average acceleration of 1-g, the Maglifter track will be approximately 10,000 ft. long. The baseline system assumes an exposed, horizontal track constructed at a sea-level launch site. Power for the Maglifter is drawn from a large, nearby energy storage system (capacitor-like).

  - Vehicle Application Identification and Summary Description - The Argus launch vehicle is a moderate lift-to-drag ratio fuselage (circular cross section), highly reusable launch vehicle. It operates autonomously (or remotely). There is no crew cabin. It is capable of delivering and returning a 20 klb payload or 6 passengers to a 100 nmi. circular low earth orbit, due east from KSC (about 10 klb to Space Station Alpha). The fan-derived propulsion modes allow improved aborts and landing operations. Without a payload, the vehicle is capable of transcontinental self-ferry.

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- **PROPULSION SYSTEM NAME**
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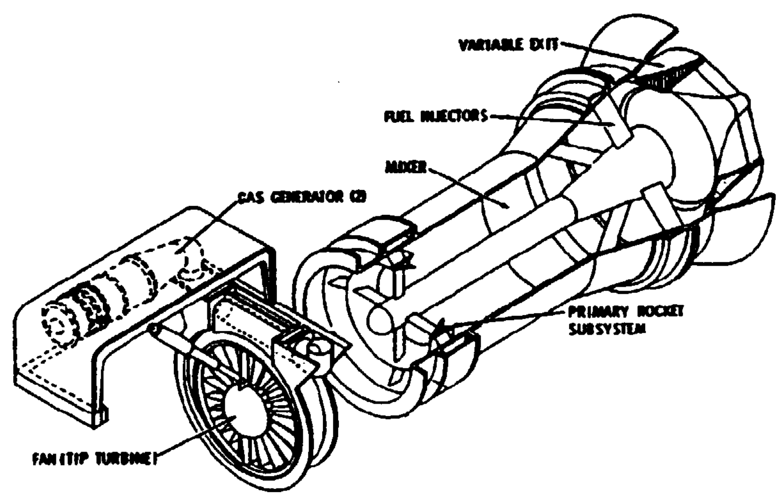
- **PROPULSION SYSTEM GRAPHICAL DEPICTION/ILLUSTRATION**



Typical Supercharged Ejector Ramjet (SERJ) Engine
(uninstalled, i.e. without inlet)

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- **PROPULSION SYSTEM SUMMARY**

ITEM, UNITS	VALUE
Sea level thrust (static, each)	328,400
Nozzle exit pressure (SLS, psia.)	14.7
Propellents	LOX/LH2
Mixture ratio (LOX/LH2)	varies, overall = 3.12
Ejector cycle	Gas Generator
Turbine temperatures (DEG F)	6200
Ejector chamber pressure (psia.)	2000
Ejector mode Isp (sec.)	varies, average ~600
Fanram/ramjet Isp (sec.)	varies, average ~2750
Rocket mode Isp, vac. (sec.)	462
Sea level static engine thrust/weight (installed)	21.3

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- **SUMMARY CHARACTERIZATION OF PROPULSION SYSTEM-VEHICLE SYSTEM "INTEGRATION" REQUIREMENTS**
  - Description: Twin engines are mounted in the wing roots close to the fuselage. Note that avoidance of scramjet modes eliminates dominant propulsion/airframe integration issues. Normal boiling point LOX and LH2 from the main propellant tanks (~25 psi) are pump-fed to each engine. Pumps are driven by a gas-generator/turbine system. Oxidizer is supplied directly to a manifold for the rocket primaries (when in use) and a small portion to the GG. LH2 fuel is used to regeneratively cool the engine, then is supplied to the rocket primaries or the secondary fuel injectors as needed. A small quantity of LH2 is also provided to the GG. The rocket primaries operate at a relatively moderate chamber pressure (~1500 - 2000 psi). Helium is used to provide tank back pressure during ascent and tank purge on orbit.
  - Nominal Mass: 22.6 klbm uninstalled, 30.7 klbm installed (both engines and inlets only)

    Nominal Thrust/Weight: ~30:1 uninstalled, ~21:1 installed (thrust taken at sea-level static conditions)
  - Other Propulsion Systems Required for Vehicle Operations: 1) Maglifter launch assist system provides initial 800 fps velocity increment, 2) Combined aft OMS/RCS (pump-fed) uses a separate set of LOX/LH2 spherical storage tanks and provides a 500 fps on-orbit plane change, orbit shaping, and deorbit ΔV and rear attitude control, 3) forward RCS (pressure-fed) uses a separate set of LOX/LH2 propellant tanks and a single He pressurant sphere near the nose of the vehicle for forward attitude control.

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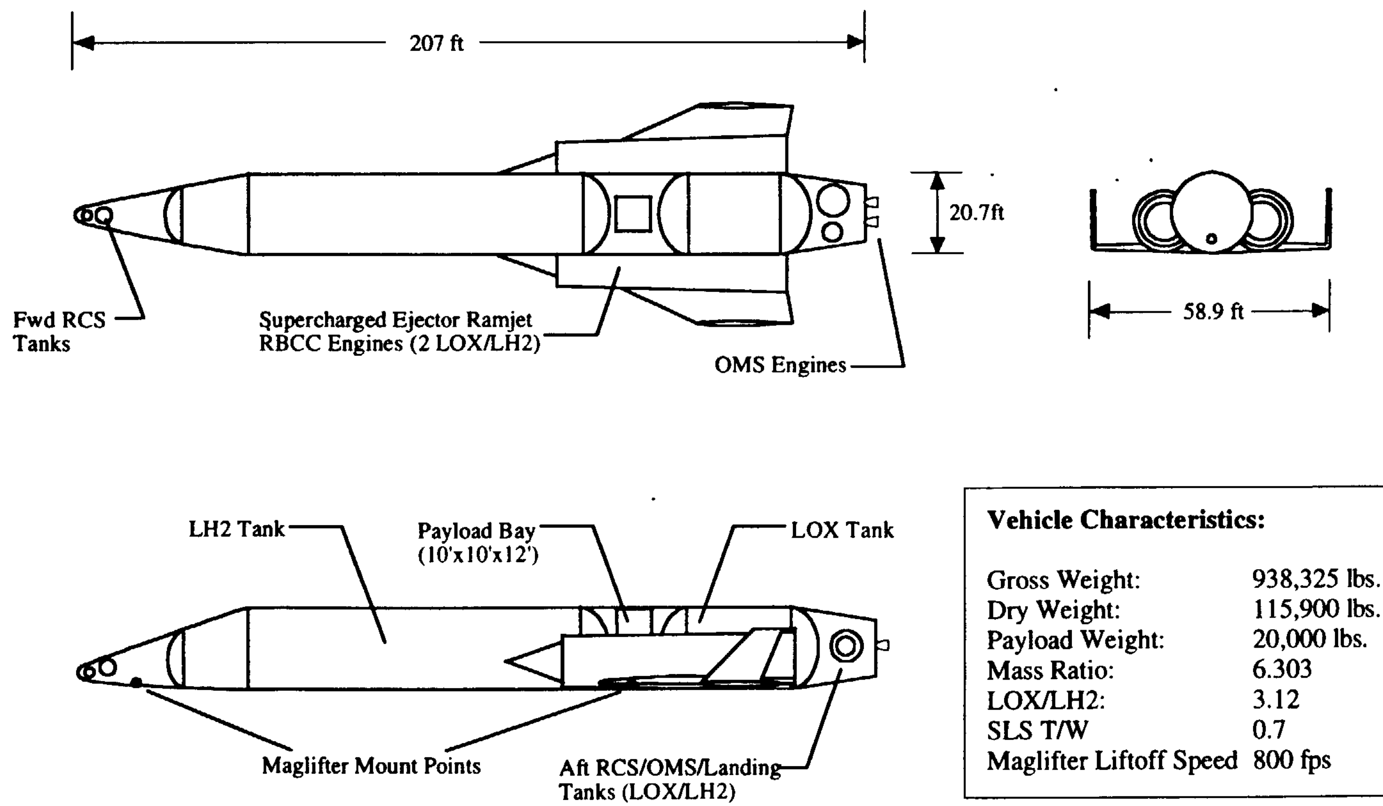
- **NOTIONAL VEHICLE SYSTEM GRAPHICAL DEPICTION/ILLUSTRATION**



Vehicle Characteristics:

Gross Weight:	938,325 lbs.
Dry Weight:	115,900 lbs.
Payload Weight:	20,000 lbs.
Mass Ratio:	6.303
LOX/LH2:	3.12
SLS T/W	0.7
Maglifter Liftoff Speed	800 fps

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- **NOTIONAL VEHICLE SYSTEM SUMMARY**

ITEM, UNITS	VALUE
Vehicle description	RBCC SSTO with 800 fps ground-based Maglifter launch assist
Orbit	100 nmi circ, 28.5° from KSC
ΔV needed	33,240 fps (with all losses)
Mission average Isp/I*	561sec./395 sec.
Payload	20,000 lb.
Payload bay	10 ft. x 10 ft. x 12 ft.
Vehicle Sea-level static T/W	0.7 (initial)
GLOW	938,325 lb.
Dry weight	115,900 lb.
Dry weight growth margin	15%
Operability/Excess margin	0% (initially)
Engines	2 supercharged ejector ramjets (SERJ RBCC)
Tanks	Gr/Ep w/metal liners, fil. wound, integral

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- **PROPULSION SYSTEM OPERATIONAL MODES AND PERFORMANCE CHARACTERIZATION**

  DESCRIPTION:
  - From just prior to release from the Maglifter (about a 5 second startup, thrust verify phase) to about Mach 2, the twin SERJ RBCC engines are operated in supercharged ejector mode (rocket primaries ON, secondary fuel injectors ON, supercharging fan ON).
  - At Mach 2, the rocket primaries are turned off and the engines operate as fan-ramjets.
  - At Mach 3, the fans are windmilled in place and the engines operate as a traditional ramjets to about Mach 6 (along a 1500 psf dynamic pressure boundary).
  - From Mach 6, the secondary fuel injectors are retracted, the inlets are closed, and the engines operate as high expansion ratio rockets.
  - For powered landing operations, the engine can be operated in low thrust, high Isp "fan-only" mode. This mode provides up to 5 minutes of powered landing time at full throttle.

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- **PROPULSION SYSTEM OPERATIONAL MODES AND PERFORMANCE CHARACTERIZATION**

Y/N? Y Ground Launch Assist
- Transition to *super/ejector* Mode — Altitude 0 (kft) — Velocity 0.8 (Mach.)

Y/N? Y Rocket/Ejector (Early Phase) — PROPULSION SYSTEM Thrust/Weight ~30 — Average Isp 600 (sec.)
- Transition to *fan-ramjet* Mode — Altitude 50 (kft) — Velocity 2.0 (Mach.)

Y/N? N Turbofan (Early Phase)

Y/N? N In-Flight Launch Assist

Y/N? Y Supercharged Ramjet — PROPULSION SYSTEM Thrust/Weight ~18 — Average Isp 3500 (sec.)
- Transition to *ramjet* Mode — Altitude 80 (kft) — Velocity 3.0 (Mach.)

Y/N? Y Ramjet — PROPULSION SYSTEM Thrust/Weight ~16 — Average Isp 2700 (sec.)
- Transition to *rocket* Mode — Altitude 100 (kft) — Velocity 6.0 (Mach.)

Y/N? N Scramjet

Y Rocket (Final Phase) — PROPULSION SYSTEM Thrust/Weight ~25 — Average Isp 465 (sec.)

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- **PROPULSION SYSTEM NAME:**
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- **OVERALL PROPULSION SYSTEM TECHNICAL MATURITY (TRL LEVEL)**
  - 4

ASSESSMENT OF MAJOR PROPULSION SYSTEM ELEMENTS:

- **ELEMENT NAME: Supercharging Fan (tip-driven)**
  - Applicable fans in this size and class were tested in mid-1960's. Some evidence supporting high speed windmilling exists. "Simulated" fans in direct-connect tests have shown performance advantage in supercharged modes.
  - Approximate Number of discrete LRU's comprising the Element = ~5
  - Critical Technology Requirements = windmilling and cooling fan at high Mach numbers
  - Current Element Technical Maturity (TRL Level) = 9 (fans in required class), 5 (windmilling/cooling)
  - Projected Degree of Difficulty for R&D to Achieve TRL 6 = B
- **ELEMENT NAME: Integration of Existing Technologies into Flight-weight SERJ Engine**
  - Ground testing of combined-cycle engines was accomplished in the mid-1960's and early 1970's (boilerplate). Additional ground and flight testing is currently underway (NASA MSFC ARTT program). One contractor proposes testing supercharged ejector ramjet variant (SERJ, Marquardt).
  - Approximate Number of discrete LRU's comprising the Element = ~200
  - Critical Technology Requirements = integration of existing technologies, testing and validation of integrated system
  - Current Element Technical Maturity (TRL Level) = 4
  - Projected Degree of Difficulty for R&D to Achieve TRL 6 = B

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  - Critical Technology Requirements = windmilling and cooling fan at high Mach numbers
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- **DESCRIPTION OF OVERALL PROPULSION SYSTEM OPERATIONAL SCENARIO**
  - After landing, the RBCC engines must be safed, purged, and inspected. Extensive on-board diagnostics are provided to help ground personnel determine engine health (integrated health monitoring). Lower turbine operating temperatures and pressures (and the elimination of protective coatings) should significantly reduce engine checkout and inspection compared to SSME.

- **PROPULSION SYSTEM UTILIZATION PROJECTIONS**
  - Total Number of Uses Per Engine Between Scheduled Servicings = ~100
  - Total Number of Uses Per Engine = ~500

- **PROPELLANTS REQUIRED (LIST ALL, INCLUDING ATMOSPHERIC GASES)**
  - Propellant 1 = Liquid Oxygen (LOX)
    - cryogenic, special handling
  - Propellant 2 = Liquid Hydrogen (LH2)
    - deep cryogenic, flammable (hazardous handling)
  - Propellant 3 = Atmospheric oxygen (air)
    - non-hazardous, not tanked

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- **PROPULSION SYSTEM SUPPORT GROUND FACILITIES REQUIRED**
  - FACILITY NAME - Maglifter track/sled maintenance and inspection depot
    - Facility to house personnel and inspection/repair equipment for Maglifter launch assist sleds and track. Typical requirements might include track test and inspection, debris removal, magnetic coil alignment, and sled test and maintenance.
    - Ground Personnel Required = ~5
  - FACILITY NAME - Flight vehicle/engine inspection and service facility (OPF-like)
    - Facility to house/shelter Argus flight vehicles between missions, provide pre-flight checkout, routine maintenance, inspection, and repair. Equipment will be available to remove/replace engines in case of component failure or scheduled overhaul. Engines will be returned to manufacturer's facility for major repairs/overhaul.
    - Ground Personnel Required = ~15
  - FACILITY NAME - Flight vehicle/Maglifter mate facility (MDD-like)
    - Crane/cradle system to effect pre-launch mate of Argus flight vehicle to Maglifter sled. Tractor system will tow Argus to mate facility using nosegear tow bar.
    - Ground Personnel Required = ~3

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REFERENCE

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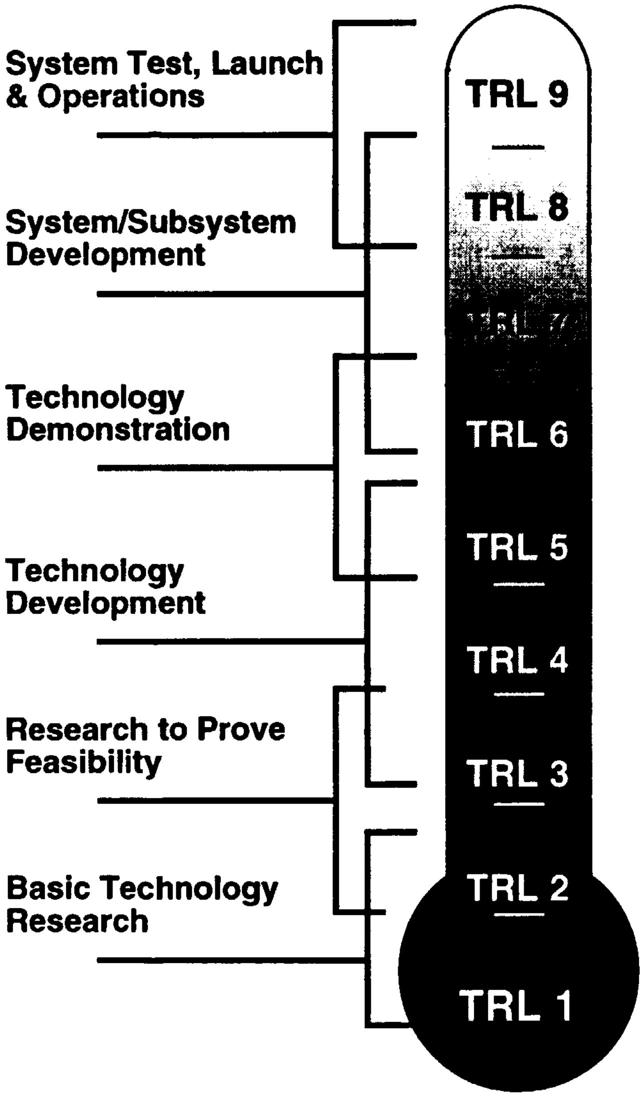
PROPULSION INFORMATION WORKSHEET – TECHNOLOGY READINESS LEVELS



Actual system "flight proven" through successful mission operations

Actual system completed and "flight qualified" through test and demonstration (Ground or Flight)

System prototype demonstration in a space environment

System/subsystem model or prototype demonstration in a relevant environment (Ground or Space)

Component and/or breadboard validation in relevant environment

Component and/or breadboard validation in laboratory environment

Analytical and experimental critical function and/or characteristic proof-of-concept

Technology concept and/or application formulated

Basic principles observed and reported

REFERENCE

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PROPULSION INFORMATION WORKSHEET – DEGREE OF DIFFICULTY IN R&D

DDR&D	DESCRIPTION
A	**Very low degree of difficulty anticipated in achieving research and development objectives for this technology;** only a single, short-duration technological approach needed to be assured of a high probability of success in achieving technical objectives in later systems applications
B	**Moderate degree of difficulty anticipated in achieving R&D objectives for this technology;** a single technological approach needed; conducted early to allow an alternate approach to be pursued to be assured of a high probability of success in achieving technical objectives in later systems applications
C	**High degree of difficulty anticipated in achieving R&D objectives for this technology;** two technological approaches needed; conducted early to allow an alternate subsystem approach to be pursued to be assured of a high probability of success in achieving technical objectives in later systems applications
D	**Very high degree of difficulty anticipated in achieving R&D objectives for this technology;** multiple technological approaches needed; conducted early to allow an alternate system concept to be pursued to be assured of a high probability of success in achieving technical objectives in later systems applications

Argus

An End-to-End Assessment of a HRST-class Vehicle with Maglifter Launch Assist

Dr. John R. Olds

Peter Bellini, David McCormick, Patrick McGinnis

Georgia Tech Aerospace Engineering

Aerospace Systems Design Laboratory

March 12-13, 1997

Phase 2 HRST Project Intro

A contracted effort to determine the influence of <u>five</u> key design variables on the performance of a reference SSTO HRST concept

Design Variables

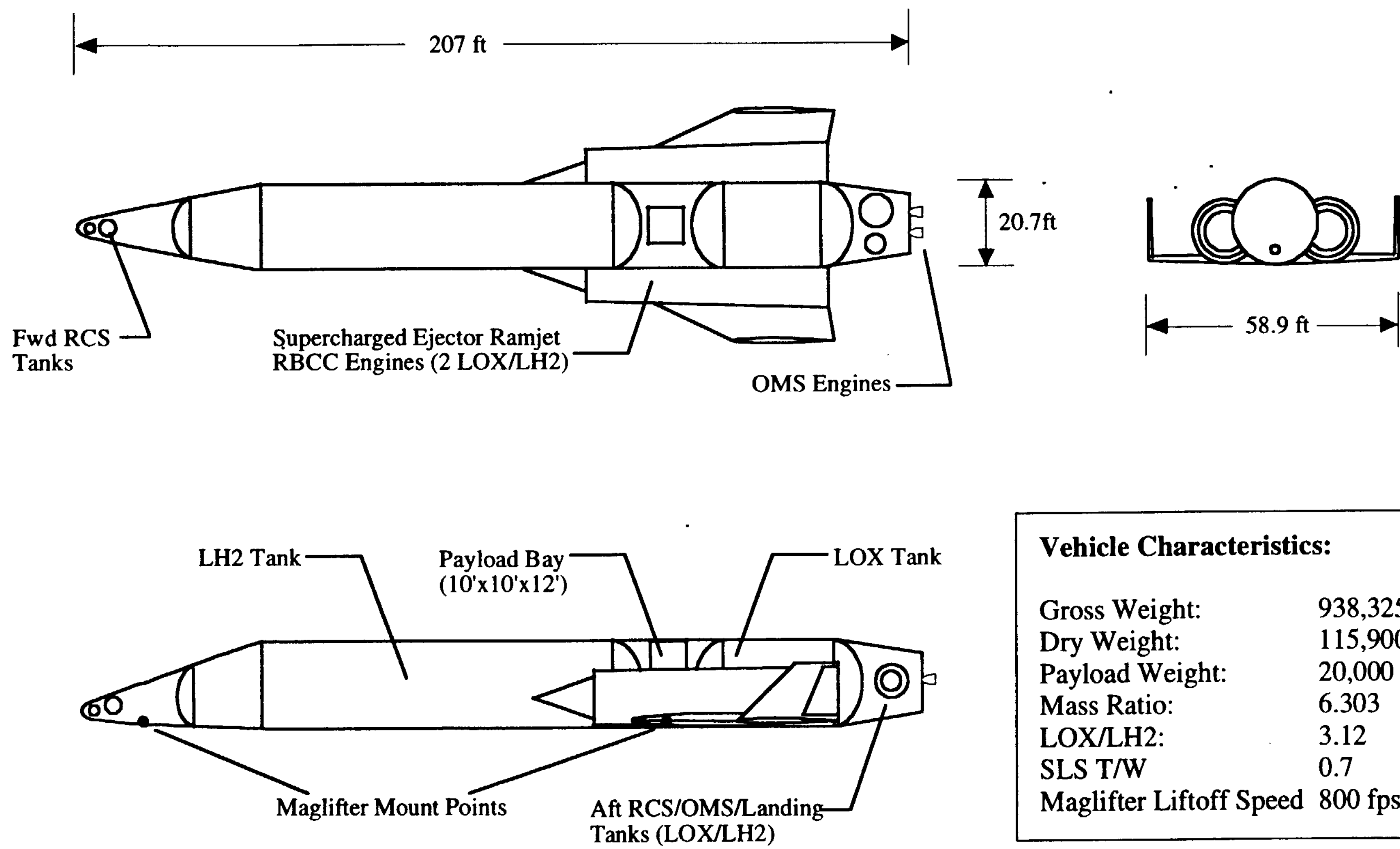
1-3. Launch Assist Parameters
  - » Maglifter release conditions (velocity, altitude, flight path angle)

4. Transition Mach Number (airbreathing to rocket)
  - » focus will be on the Mach 5 - 10 range

5. Combination vs. Combined-Cycle Propulsion
  - » separate vs. integrated rocket and airbreathing engines

Baseline Argus Concept
(preliminary results)

Argus Concept



Vehicle Characteristics:

Gross Weight:	938,325 lbs.
Dry Weight:	115,900 lbs.
Payload Weight:	20,000 lbs.
Mass Ratio:	6.303
LOX/LH2:	3.12
SLS T/W	0.7
Maglifter Liftoff Speed	800 fps

jro/3.97/4

Argus Highlights

- Maglifter Launch Assist
  - » reduce overall ΔV required of vehicle by 600 - 1200 fps
  - » reduce take-off gear weight
  - » ground-based 'staging' infrastructure (power, track, etc.)
- SERJ RBCC Main Propulsion
  - » increase effective trajectory Isp (lower propellant weight)
  - » multi-mode operation integrated into one engine class
  - » Mach 6 transition to rocket-mode eliminates scramjet

Argus Highlights (2)

- Circular Body Airframe (moderate lift/drag)
  - » reduce structural weight (simpler load paths)
  - » easier, lower cost manufacture

- Lightweight Materials and Subsystems
  - » reduce vehicle weight and footprint
  - » graphite/PEEK tanks (w/metal liners), Ti-Al, Ti-Al/Si-C
  - » all passive TPS (SHARP, large block metallic, TABI)
  - » high power density fuel cells, EMA's, adv. avionics

Argus Highlights (3)

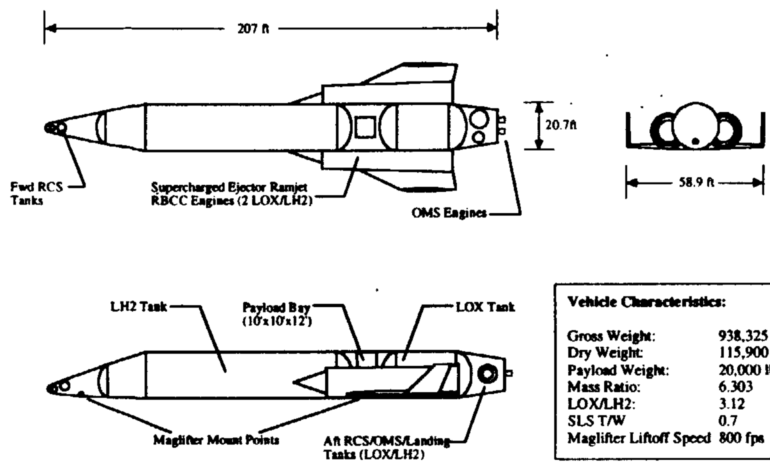
- Long Life, Highly Reusable Flight Hardware
  - » lower recurring costs (LRU's, maintenance, operations)
  - » 250 flight airframe life, 125 flight RBCC engine life
  - » built-in test (BIT) & vehicle health monitoring (VHM)
  - » 15% dry weight margin for growth

- Safe, Flexible Operations
  - » SERJ engine increases abort options (fan-related modes)
  - » powered landing (go-around capability)
  - » self ferry between landing & launch sites (high speed cruise)

Baseline Argus Weights

Name	Weight (lbs)
Wing and Tail Group	15,175
Body Group (incls. tanks)	28,080
Thermal Protection	6,360
Main Propulsion	34,310
OMS/RCS Propulsion	2,675
Subsystems and Other Dry Weights	14,180
Dry Weight Margin (15%)	15,120
Dry Weight	115,900
Payload	20,000
Other Inert Weights (residuals, etc.)	12,970
Insertion Weight	148,870
Ascent Propellants	789,455
Gross Lift-off Weight	938,325

Baseline Argus Summary



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SLS T/W	0.7
Maglifter Liftoff Speed	800 fps

Vehicle:

payload = 20 klb to 100 nmi. circular orbit @ 28.5°
dry weight = 115.9 klb
gross weight = 938 klb

Propulsion:

2 Supercharged Ejector Ramjet (SERJ) RBCC engines
Isp @ sea level = 446 sec. (LOX/LH2)
I* = 395 sec. (for baseline trajectory)
thrust @ sea level =328 klb/ea. (sized for T/W = 0.7)
engine installed T/W = 21.4 (prior to weight margin)

Vehicle Technologies:

Mach 6 capable supercharged ejector ramjet engines
integral graphite/PEEK honeycomb LH2 tank (w/liner)
graphite/PEEK overwrapped LOX spheres (w/liners)
titanium-aluminide/Si-C hot structure (wings, etc.)
SHARP/Metallic (large block)/TABI passive TPS
cryogenic O2/H2 OMS/RCS
electro-mechanical surface actuators

Trajectory/Operational Modes:

Maglifter horizontal acceleration to 800 fps @ sea level
supercharged ejector mode to Mach 2
fan-ramjet mode to Mach 3
ramjet mode to Mach 6 (const. dyn. press. = 1500 psf)
built-in RBCC rocket mode to orbit (Isp = 462 s vac)
horizontal landing

Notes and Issues:

- fully autonomous (no pilots), up to 6 passengers can ride in module in cargo bay
- concept avoids use of scramjet airbreathing mode (and associated development costs)
- Mach 6 transition to rocket avoids severe aeroheating problems (all passive TPS)
- large block metallic TPS on (circular body) windward fuselage, simplifies installation & maintenance
- SERJ RBCC engine builds on historical development
- Maglifter development and infrastructure costs remain to be determined

Phase 2 HRST Research

Key Questions

While the baseline concept looks promising, several key questions remain to be answered

1. What is the ultimate benefit of the Maglifter?
   » what are the preferred launch velocity, flight angle, altitude?

2. When should the vehicle transition to rocket?

3. Is *combined-cycle* better than *combination* propulsion?
   » integrated synergistic vs. separately optimized prop. systems

Research Goal

Determine the influence of the five ascent parameters on the following three characteristics of the reference HRST concept

1. Vehicle Payload Capability
   - » for fixed (weight) margin and propellant load
2. Vehicle Dry Weight (resized)
   - » for fixed margin and payload
3. Vehicle Margin
   - » for fixed payload and propellant load